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TITLE – Exposure Decisions for a Lunar Flyby Contingency Mission

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ABSTRACT

A determination is made of optimum exposure settings for a recommended sequence of photographic activity suitable for lunar flyby. The sequence is based upon nominal launch vehicle trajectories for July 1966 and is applicable to any Lunar Orbiter mission where there is failure to inject into lunar orbit.

The technique used for selecting camera exposure time is applicable to the broad class of non-standard operational situations where image motion compensation is not obtainable.

(NASA-CR-153774) EXPOSURE DECISIONS FOR A LUNAR FLYBY CONTINGENCY MISSION (Bellcomm, Inc.) 15 p

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BELLCOMM, INC.

SUBJECT: Exposure Decisions for a Lunar Flyby Contingency Mission - Case 340

DATE: March 3, 1967

FROM: D. D. Lloyd

TM-67-1012-3

X67-36140

TECHNICAL MEMORANDUM

INTRODUCTION

During Lunar Orbiter mission simulations at JPL in June 1966, a number of non-nominal events were simulated. The non-nominal occurrence of a failure to inject into lunar orbit was exercised under two circumstances: (1) where a propulsion failure occurred at midcourse, and (2) where a failure occurred at the start of injection.

Some planning for such non-nominal conditions had been undertaken prior to mission simulation and it was readily agreed by all operational personnel that photography should be attempted during flyby. However, this planning had been in general terms, i.e., "perform photographic flyby mission"* and had not been exercised in terms of detailed specific operational activities and command preparation. The simulation exercise indicated that without such detailed planning it was not possible to prepare and transmit the necessary commands from the SFOF (Space Flight Operations Facility) to the spacecraft.

As a result of the simulation exercises, the Lunar Orbiter Project Office decided that a detailed preparation of a flyby photographic sequence should be undertaken. An optimum sequence of photographic operations should be determined. The required photographic operational sequence would be converted into commands.

Clearly the actual trajectory data is not available prior to the mission. Furthermore the commands to be sent to the spacecraft, which include the time of photography and the magnitude of the maneuvers, must correspond to the actual trajectory conditions. Therefore the actual commands to be transmitted cannot be finalized prior to the mission. However, modification of the commands is a minor activity compared to determination of the flyby tactics and preparation of the

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*Off-Nominal Mission Possibilities for Lunar Orbiter, Bellcomm TM-65-1012-8, September 15, 1965, F. N. Schmidt.

[redacted]

commands. It was, therefore, decided to prepare a detailed sequence of photographic operations based upon some specific trajectory data for some specific sun (lighting) conditions. Commands would then be prepared for these conditions. These commands would then be modified in real time.

Because one cannot outguess the actual trajectory, "nominal"* trajectories were chosen because of the convenience of available data on these. The four July launch opportunities were used to generate the necessary detailed trajectory data. A determination of a sequence of recommended photographic operations is presented below.

TECHNICAL DISCUSSION

Trajectories Considered

Trajectory data was provided by the Lunar Orbiter Project Office for the four launch opportunities of July 1966. (Table 1). The data of Table 1 was used to draw Figures 1 through 4, which are plots of the trajectories in terms of polar coordinates. Figure 1 corresponds to July 12, Figure 2 to July 13 and so forth. It is clear that these represent a broad variation of altitudes and of sections of the backside of the moon. These are considered to represent a sufficiently broad range of conditions to cover all "nominal" trajectories for all launch days of all months. They may not be representive for non-nominal Atlas-Agena launch vehicle trajectories.

The operational decisions are: (1) when to take photos, with the associated decision of camera maneuvers; and (2) the camera shutter exposure time.

A simple inspection of the situation indicated that it was relatively easy to obtain coverage of a large portion of the backside of the moon under many alternative plans. The determination of camera maneuvers and exposure time to obtain the highest quality photographs was, therefore, analyzed first.

Determination of Optimum Lens Shutter Exposure Time

The attached Table 2 was prepared to enable evaluation of the predicted photo quality under different alternate decisions. Data is provided for each shutter speed for a variation of phase angle (g). The range of phase angles between 80° and 40° is considered. Phase angles smaller than 40° would require the solar panels to be off-sun more than 30° (see Figure 5), which is inadvisable.

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*Nominal prior to injection burn.

The anticipated resolution is tabulated. In considering the data presented in Table 2, for derivation of resolution ignoring smear, the value of g = 50° is a useful point of departure. At this phase angle the signal to noise (s/n) is essentially the same for all shutter speeds. Futhermore the s/n is 3 (about the detection value) for a nominal one meter cone at 46 km. For higher altitudes the resolution is decreased proportionately; for example, at an altitude of 500 km the resolution is degraded by a factor of 500 km divided by 46 km, i.e., 11. The value of s/n is taken from Figure 7 (from Boeing Co.).

The value of the signal-to-noise ratio is converted to an estimate of resolution by the equation;

$$\text{resolution} = (1/3 \cdot 3/n)^{-1/2} \qquad \text{(meters)}$$

This method of calculation neglects smear and the variation in the modulation transfer function. The values of resolution are appropriate to a 46 km altitude.

The effects of smear are next examined. When stated in terms of ground motion during exposure, it is easy to see that smear depends only on velocity and exposure time, when no image motion compensation is used.* A velocity to 2 km/sec is used for the smear estimated in this table.

The expected resolution without smear, is compared to the expected smear. Some judgment is involved in combining these. An arrow is used to indicate at what non-smear value the resultant smeared image is expected to be optimum. This defines the altitude above which the smear is tolerable for each shutter speed.

From the point of view of optimum photography, the shutter speeds can now be selected on the basis of the data tabulated in Table 2. The selected speeds are shown in Table 3.

Photo Sequence Recommended by Project

The number of photographs that can be taken during flyby is limited to a maximum of 9 by hardware constraints. The camera looper can hold up to 20 photographs. Eleven photograph lengths of leader must be advanced to bring the first film into the camera. A sequence of 9 photographs is recommended.

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*IMC cannot be used in flyby because the altitude is too high (beyond 250 km). It is interesting to note that this method of determining smear is also useful in other cases, e.g., oblique photography to a point greater than 200 km away.

The Lunar Orbiter Project Office recommended that the last of these be used to photograph the Earth. Six photographs at intervals of 10° in phase angle (90°, 80°, 70°, 60°, 50° and 40°) were recommended by the Lunar Orbiter Project Office with two additional photographs being taken at 70° to exercise all three shutter speeds at one phase angle. It is notable that photographs 7 to 8 will nominally cover the full lunar disc in the moderate resolution frame.

To obtain useful film response on the first (terminator) photograph a delay to 2° past the terminator was suggested. Taking these recommendations and applying the exposure decisions discussed above, the following exposure values are obtained.

Frame #	Phase Angle	Exposure Time
1	88°	1/25 sec
2	80°	1/25 sec
3	70°	1/25 sec
4	70°	1/50 sec
5	70°	1/100 sec
6	60°	1/100 sec
7	50°	1/100 sec
8	40°	1/100 sec

Douglas D. Lloyd

1012/DDL/dmc D. D. Lloyd

Attachments
Tables 1-3
Figures 1-7

TABLE 1 TRAJECTORY DATA

DATE	INJECTION			TERMINATOR			g = 70			g = 50			PERILUNE		
JULY	LONG LAT	TIME (MIN)	ALT (Km)	LONG LAT	TIME (MIN)	ALT (Km)	LONG LAT	TIME (MIN)	ALT (Km)	LONG LAT	TIME (MIN)	ALT (Km)	LONG LAT	TIME (MIN)	ALT (Km)
12	34°E	0	900	106°E	27.6	1700	126°E	43.8	2700	146°E	74.4	5050	57°E	6	900
	12°N			1°N			1°S			9.5°S			9°N		
13	34°E	0	700	93°E	12.6	1050	113°E	22.8	1600	133°E	37.8	2650	54°E	0	700
	13°N			4°N			1°S			5°S			10.5°N		
14(15)	34°E	0	550	81°E	6.6	600	101°E	14.4	1000	121°E	23.4	1600	58°E	3	500
	12°N			8.5°N			5.5°N			2°N			12°N		
(15)16	32°E	0	450	68°E	6.0	500	88°E	12.0	750	108°E	19.2	1250	57°E	1.8	400
	11°N			12°N			10.5N			8°N			14°N		

TABLE 2

EXPOSURE (sec)	PHASE ANG. (deg)	RESOLUTION (meters) 46KM	500KM	1000KM	2000KM	4000KM	SMEAR (m)	DENSITY
1/25	80	.7	8	15	31	62	80	.56
	75	.7	8	15	31	62	80	.81
	70	.6	7	13	26	53	80	1.04
	65	.6	7	13	26	53	80	1.25
	60	.7	8	15	31	62	80	1.43
	50	1.1	12	24	48	96	80	1.7
	40	1.3	14	29	57	115	80	1.7*
1/50	80	.92	10	20	40	81	40	.31*
	75	.74	8	16	32	65	40	.45
	70	.70	8	15	31	62	40	.60
	65	.68	7.5	15	30	60	40	.75
	60	.73	8	16	32	64	40	.89
	50	1	11	22	44	88	40	1.15
	40	1.3	14	29	57	115	40	1.38
1/100	80	1.7	19	37	75	149	20	.26*
	75	1.2	13	26	53	105	20	.27*
	70	.87	10	19	38	77	20	.32*
	65	.77	8	17	34	68	20	.40
	60	.83	9	18	37	73	20	.49
	50	1.1	12	24	48	96	20	.67
	40	1.3	14	29	57	115	20	.84

*Near Fog

TABLE 3

At g = 50°

For an altitude:
300 - 3,000 km, can use 1/100
3,000 - 6,000 km, can use 1/50 or 1/100
6,000 - up, can use 1/25, 1/50 or 1/100
(But 1/100's preferred because density for 1/100 D = .6 whereas for 1/50 D = 1.1, and for 1/25, D = 1.7).

Recommend for g = 50°, or less, use 1/100 sec for all altitudes.

For g = 60° and 65°

For an altitude:
300 - 3,000 km, can use 1/100
3,000 - 6,000 km, can use 1/50 or 1/100
6,000 km and up, use 1/25, 1/50, or 1/100
(But 1/25 or 1/50 preferred due to signal/noise).

Recommend 1/50 at 60° and 1/25 at 65°.

At g = 70°

Recommend the camera shutter should be exercised at all shutter speeds, i.e., 1/25, 1/50, and 1/100.

If g > 70°, but below 80°

Recommend use of 1/50 for altitudes below 3,000 Km. Use of 1/25 for altitudes above 3,000 Km.

For g = 80° or above

Fog occurs for g = 80° or above with 1/50 sec as well as with 1/100 sec.

Recommend, for g = 80° or above, use 1/25 sec.

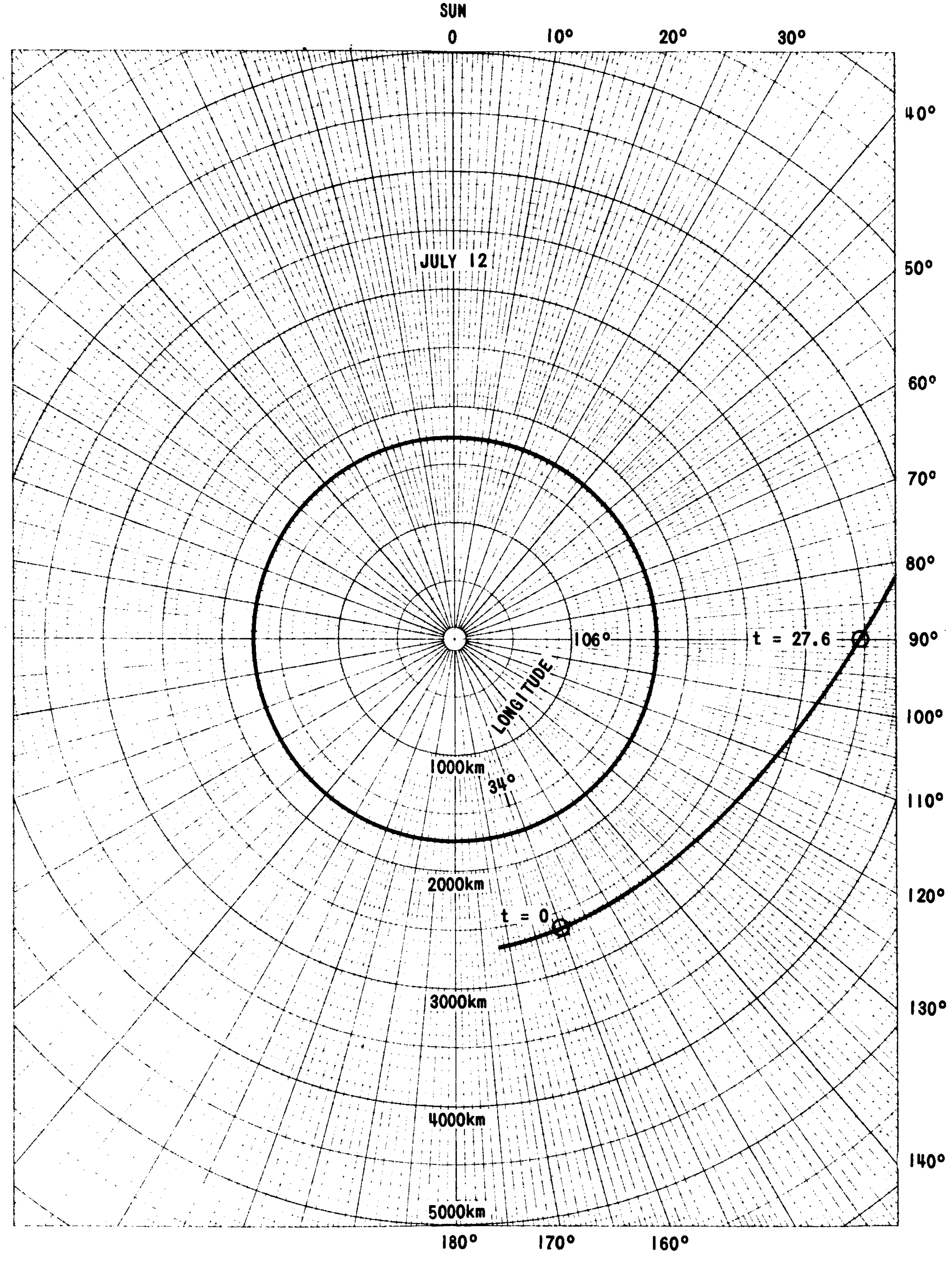
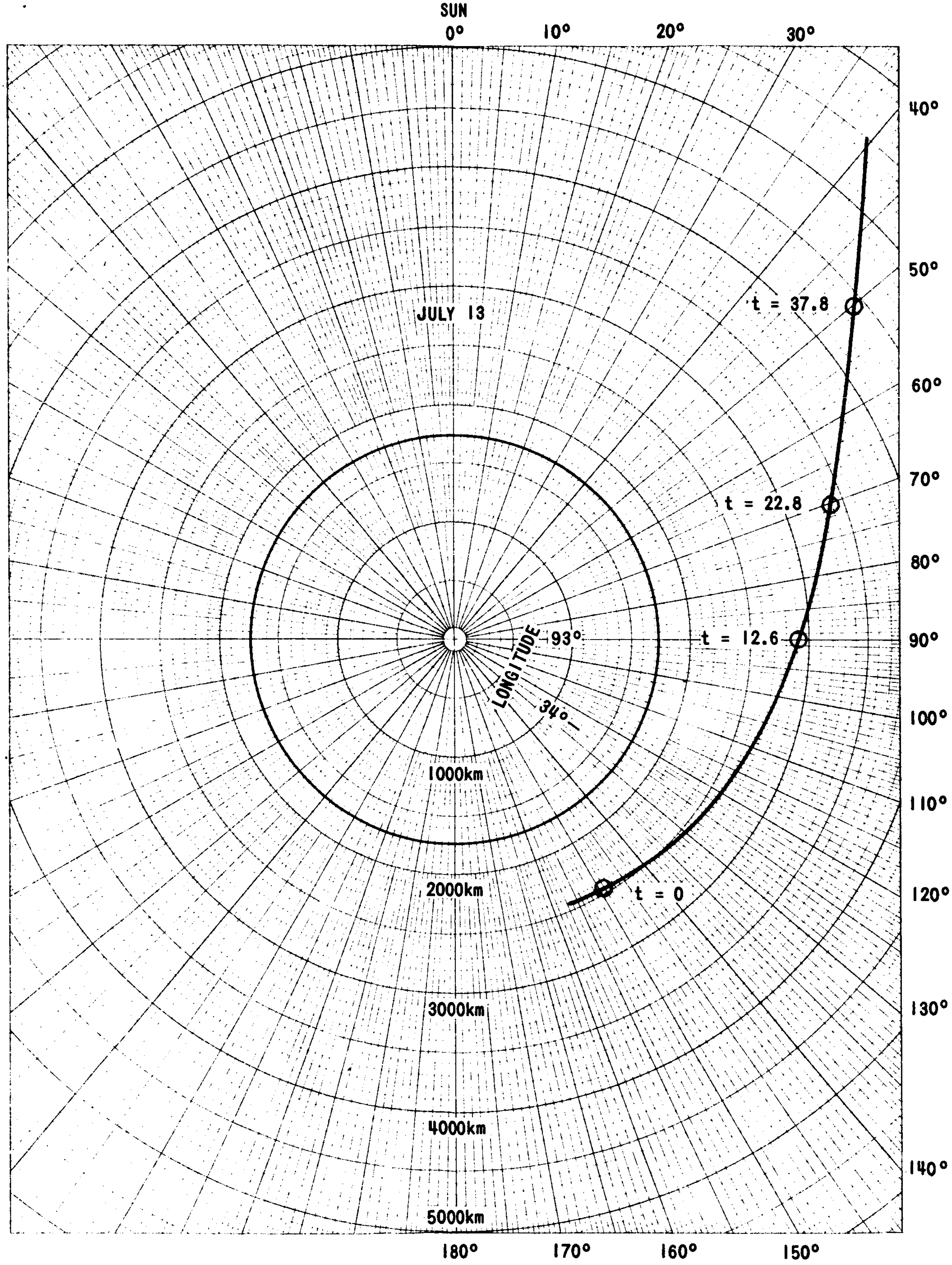

SUN
0
10°
20°
30°
40°
50°
60°
70°
80°
90°
100°
110°
120°
130°
140°
JULY 12
106°
LONGITUDE
t = 27.6
1000km
34°
2000km
t = 0
3000km
4000km
5000km
180°
170°
160°

FIGURE 1



SUN
0°
10°
20°
30°
40°
50°
60°
70°
80°
90°
100°
110°
120°
130°
140°
JULY 13
t = 37.8
t = 22.8
t = 12.6
t = 0
93°
LONGITUDE
34°
1000km
2000km
3000km
4000km
5000km
180°
170°
160°
150°

FIGURE 2

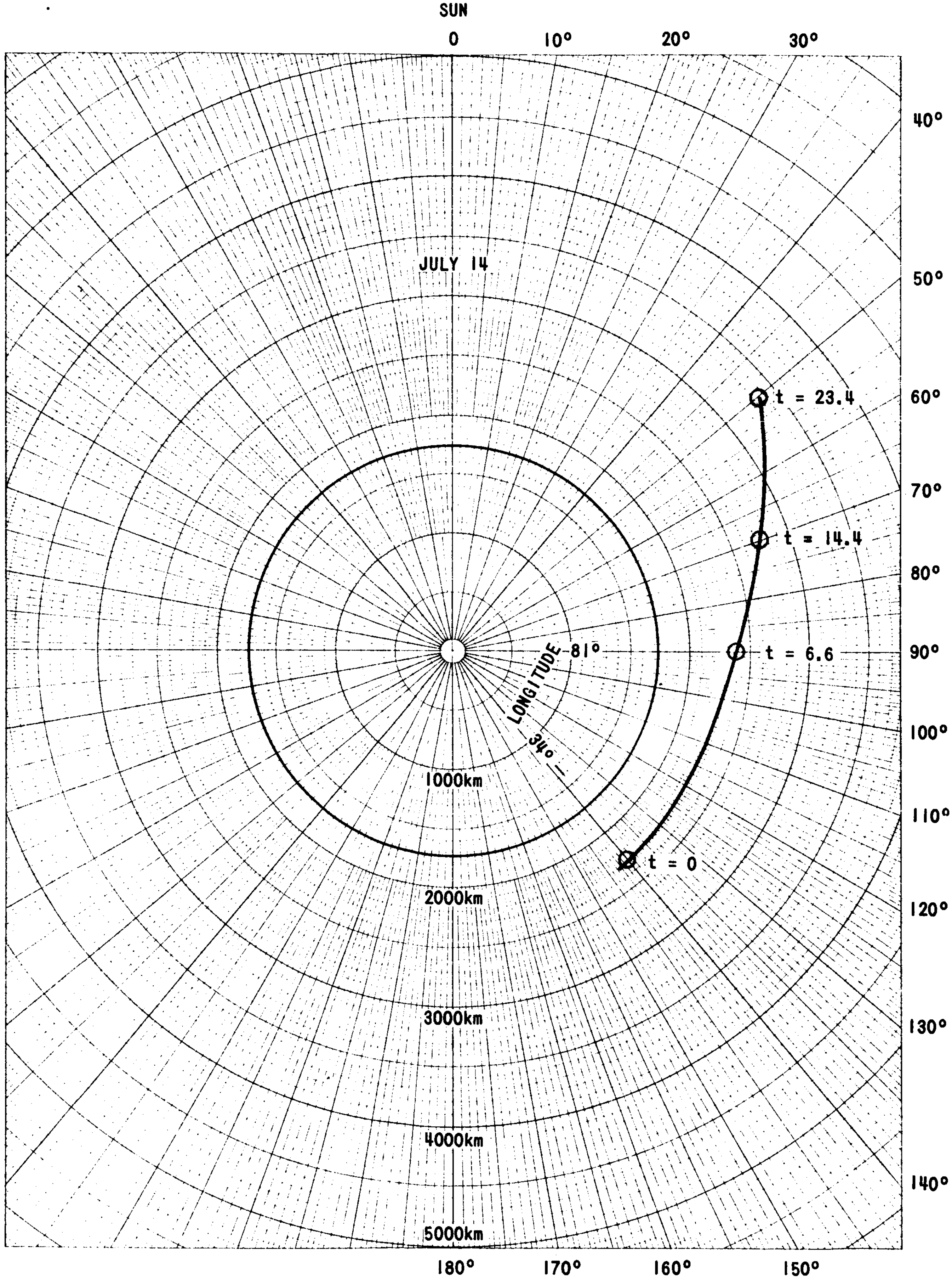

SUN
0
10°
20°
30°
40°
50°
60°
70°
80°
90°
100°
110°
120°
130°
140°
JULY 14
t = 23.4
t = 14.4
t = 6.6
t = 0
81°
LONGITUDE
34°
1000km
2000km
3000km
4000km
5000km
180°
170°
160°
150°

FIGURE 3

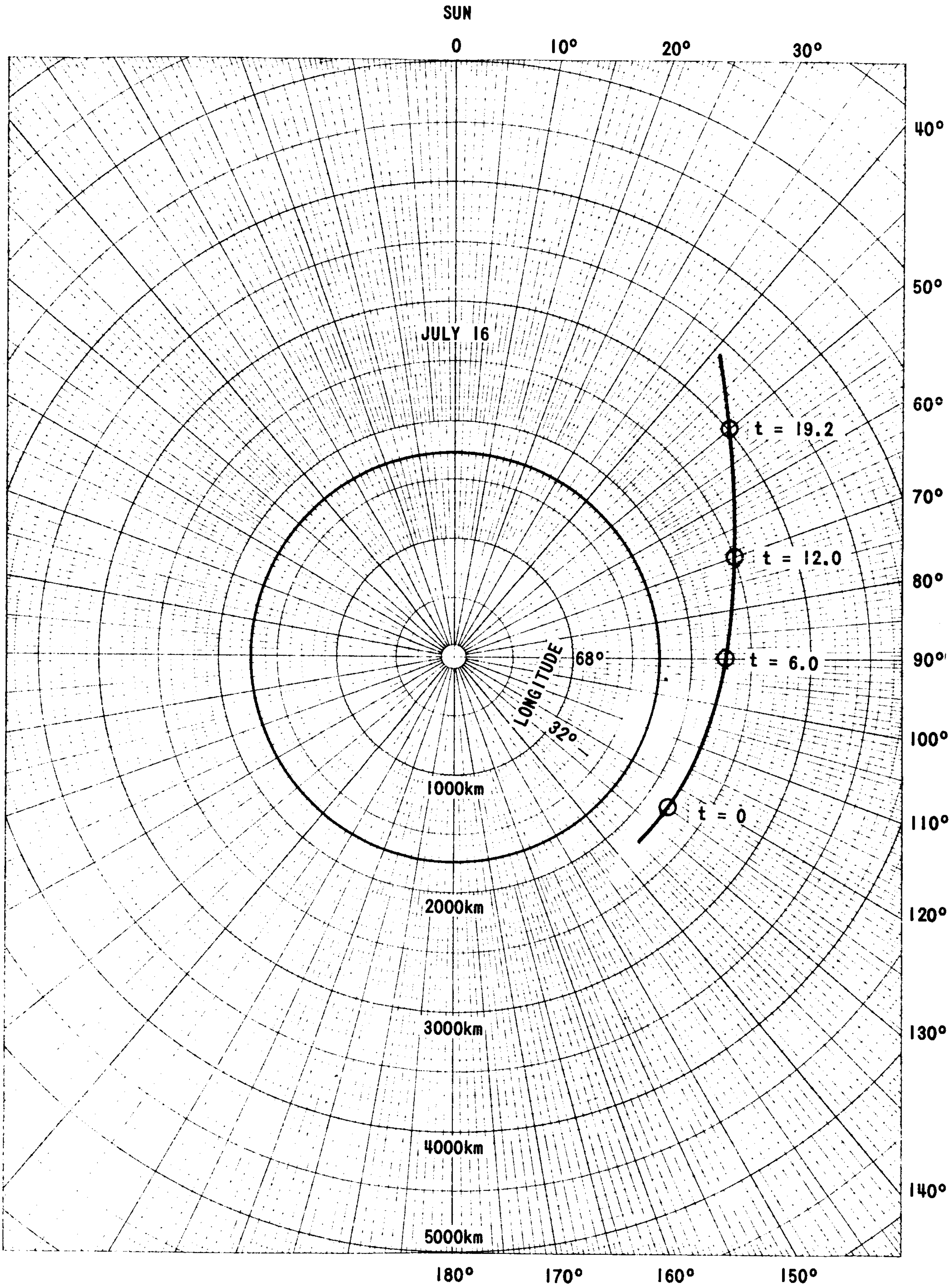

SUN
0
10°
20°
30°
40°
50°
60°
70°
80°
90°
100°
110°
120°
130°
140°
JULY 16
t = 19.2
t = 12.0
t = 6.0
t = 0
68°
LONGITUDE
32°
1000km
2000km
3000km
4000km
5000km
180°
170°
160°
150°

FIGURE 4

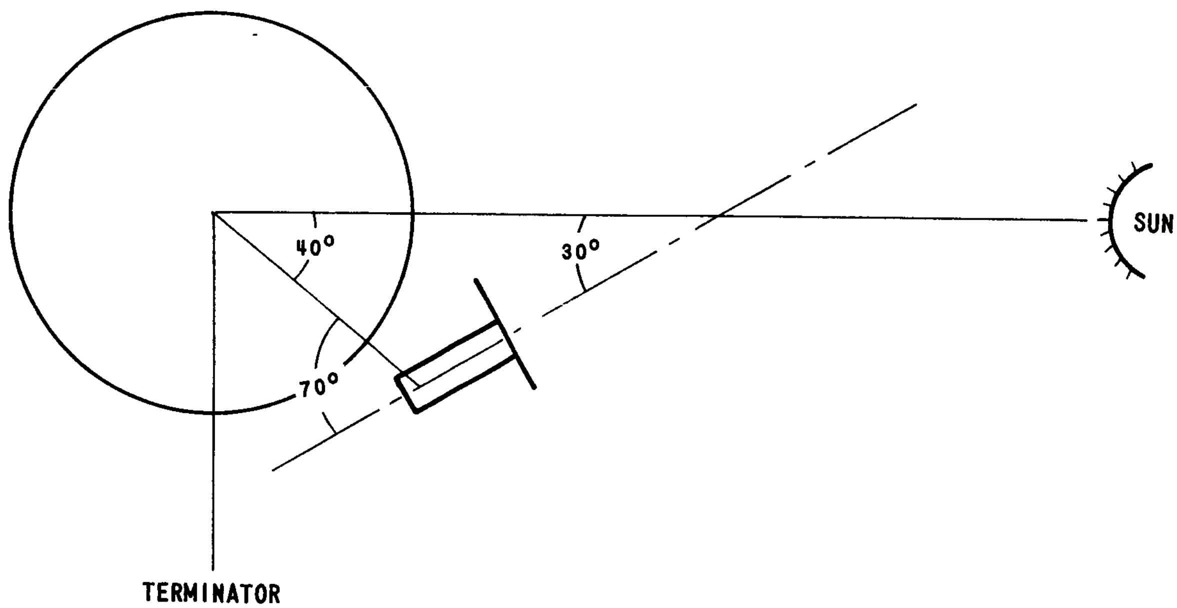


FIGURE 5 - SOLAR POWER LIMIT ON SUN ANGLE

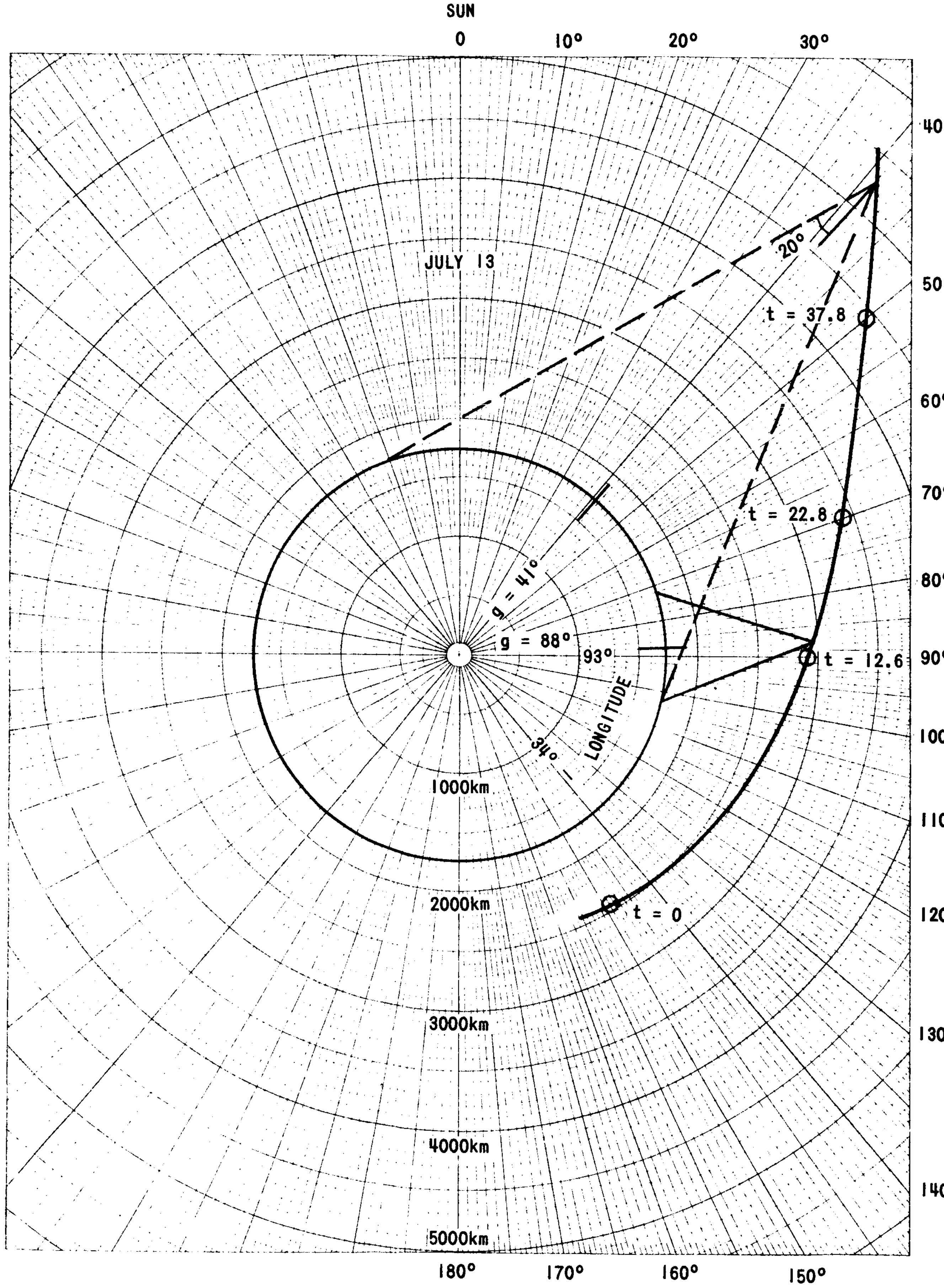

SUN
0
10°
20°
30°
40°
50°
60°
70°
80°
90°
100°
110°
120°
130°
140°
JULY 13
20°
t = 37.8
t = 22.8
t = 12.6
t = 0
g = 41°
g = 88°
93°
34°
LONGITUDE
1000km
2000km
3000km
4000km
5000km
180°
170°
160°
150°

FIGURE 6

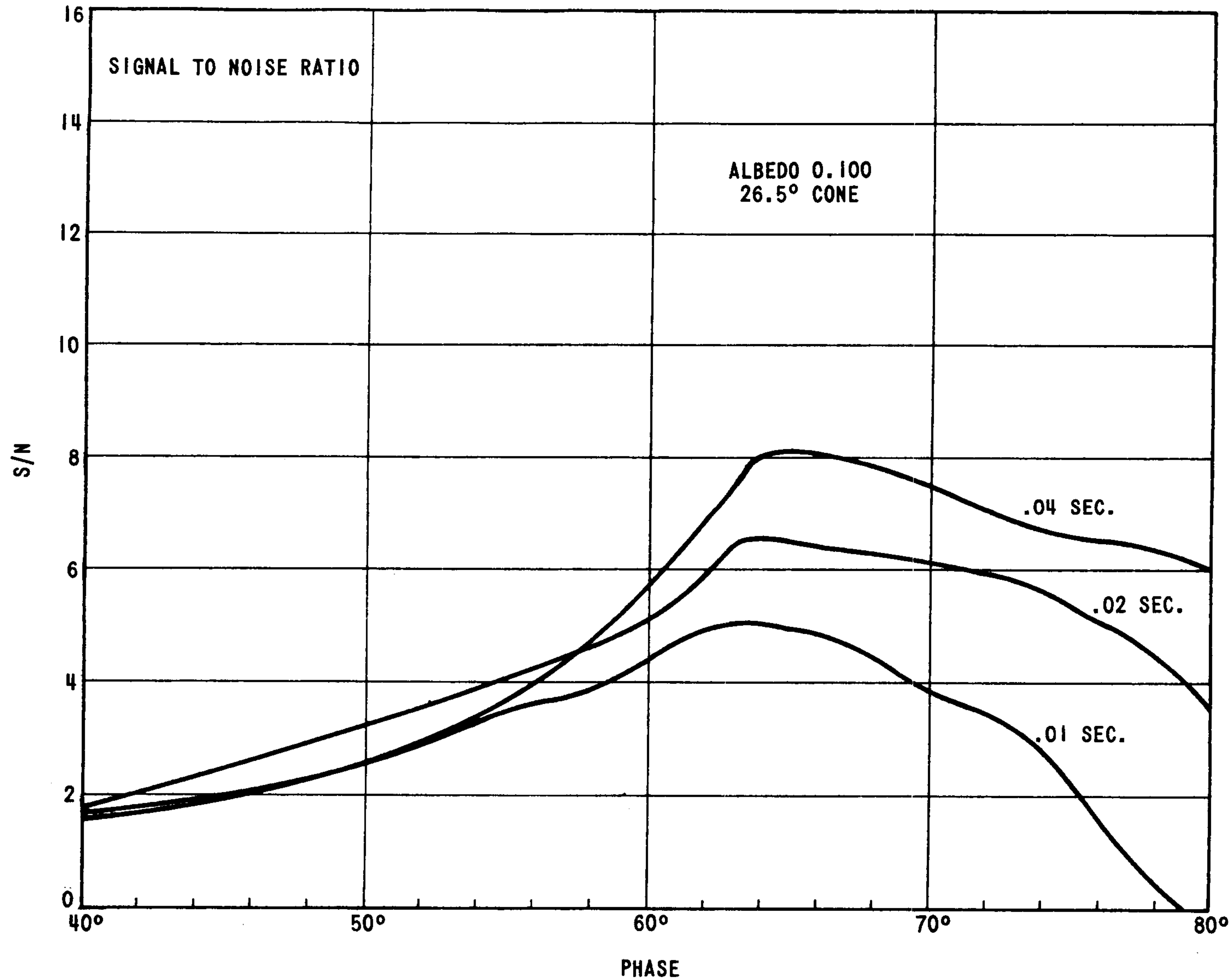

SIGNAL TO NOISE RATIO
ALBEDO 0.100
26.5° CONE
.04 SEC.
.02 SEC.
.01 SEC.
S/N
16
14
12
10
8
6
4
2
0
40°
50°
60°
70°
80°
PHASE

FIGURE 7